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Do class size reductions protect students from infectious diseases? Lessons for COVID-19 policy from a flu epidemic in Tokyo Metropolitan Area

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Abstract

We evaluate the causal effect of class size (number of students in a classroom) on incidence of class closure due to flu as an outcome of an infectious disease epidemic. For identification of causal effects, we apply a regression discontinuity design using discontinuous variation of class sizes around the class size cap set by regulation to administrative data of public primary and middle school students in one of the largest municipalities within the Tokyo Metropolitan Area from 2015 to 2017. The classroom area of 63 m^2 is set by regulation in Japan; class size reduction improves social distancing among students in a classroom. We find that class size reduction is effective to reduce class closure due to flu: a one-unit reduction of class size decreases class closure by about 5%; additionally, forming small classes with 27 students at most, satisfying the social distancing of 1.5 m recommended to prevent droplet infection including influenza and COVID-19, reduces class closure by about 90%. Moreover, we find that the older the students, the larger the effects of class size reduction. Our findings provide evidence for the effectiveness of social distancing policy in primary and middle schools to protect students from droplet infectious disease, including COVID-19.

Keywords: class size, class closure, students' health, influenza(flu) epidemic, lesson for COVID-19
JEL Classifications: I18, I21, I28

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1 Introduction

Outbreaks of communicable diseases have affected not only health outcomes but also peoples behavior and lifestyle, along with various socioeconomic outcomes. Currently, to prevent the spread of coronavirus disease 2019, known as COVID-19, national and subnational governments in many countries have decided to implement policies restricting interactions among individuals, which are believed to save human lives but have negative consequences for social and socioeconomic markers.

School closure is considered to be one such measure to control flu pandemic, as school-aged children would otherwise have the greatest frequency of daily contacts with those in the same age group during the weekdays (Ibuka et al., 2016). However, school closure would also affect students outcomes adversely, due to reduction of instruction time in schools.[1] In addition, it is known that this adverse effect is more serious for students from disadvantaged households, widening the gap in education by socioeconomic background (Bessho et al., 2021). To mitigate these adverse effects of school closure on students outcomes without exposing them to risk of infection, it is urgent to seek alternative, safe measures other than shutting down schools entirely.[2]

This paper focuses on a measure to increase the physical distance between each student in classrooms, in so-called social distancing or physical distancing, as an alternative to entire school closure. We utilize the information of class size (i.e., number of students in a classroom) as a proxy for social distancing among students in a class and examine how social distancing among students in a class affects epidemic spread of infectious disease in the class. Given the fixed area of the classroom, the physical distance between students depends on class size (student numbers): the smaller class sizes, the greater students physical distance. While social distancing in schools under outbreaks has been discussed, there is little information on the effects of social distancing policies and procedures in schools other than under prolonged school closure (Uscher-Pines et al., 2018).

To estimate the effect of class size on epidemic spread of infectious disease in the class, we use school administrative data collected by the Education Board of a city in Tokyo Metropolitan Area (hereafter, we refer to this city as City X).[3] We utilize the information of class closure due to seasonal flu as an outcome proxying a flu epidemic in classrooms. Class closure for seasonal flu

[1] As previous studies indicate positive relation between instruction time in schools and students achievements (e.g., Wößmann, 2003; Pischke, 2007; Bellei, 2009; Gary-Bobo and Mahjoub, 2013; Hansen, 2013; Kikuchi, 2014; Andrietti, 2015; Lavy, 2015; Rivkin and Schiman, 2015; Battistin and Meroni, 2016; Cattaneo et al., 2017; Bessho et al., 2019), decreased instruction time due to school closures will tend to affect students current and future outcomes negatively.

[2] One alternative is to fine-tune the rules governing school closure to reduce the risk of unnecessary school shutdown. For example, New York City set a policy for temporary school closure due to COVID-19 requiring that the source of infection be in the school (Shapiro, 2021).

[3] We anonymize the city name because the education board does not allow us to disclose the name of the city.

depends on decisions made by local stakeholders, such as municipalities and/or school directors. They consider various potential adverse effects, discussed above, and take measures according to the epidemic trend of seasonal flu. Therefore, class closure could be a useful assessment measure of a flu epidemic in classrooms (Suzue et al., 2012). To identify the causal effect of class size reduction, we apply a regression discontinuity design established by Angrist and Lavy (1999) using discontinuous variation of class sizes around the class size cap due to regulation to control for endogeneity of class sizes.

Estimation results reveal that a one-unit reduction in class size decreases class closure due to flu by about 5.2%-5.3% in comparison to the overall mean and that we could reduce class closure by about 90% if we reduced size of all classes to less than or equal to 27. Given the area of a classroom in Japan, which is 63 m^2 as set by regulations, a class size of 27 is the largest at which students can maintain physical distance of 1.5 m. The distance of 1.5 m is the threshold reducing the risk of infection due to large droplets exhaled by infected persons. Additionally, when we use a cubic function of class size and estimate class size effects, the estimation results show that the marginal effects are statistically significant at 10% at a class size of between 27 and 34. One possible interpretation of the class size effect is that class size reduction increases the physical distance between students and consequently prevents flu spread in classrooms.[4] This result also implies that once students get a certain level of physical distance, additional class size reduction is no longer effective to decrease the probability of flu infection. The results show that the older the students, the stronger the effects of class size reduction.

This paper is related to the strand of literature in education economics with special focus on the effects of class size. Many papers analyze the causal effects of class size on students' outcomes, using datasets from both experimental settings (e.g., Tennessee's Project Star) and quasi-experimental settings, like studies using a regression discontinuity design. While previous studies have focused on outcomes such as student achievement (e.g., Angrist and Lavy, 1999; Hoxby, 2000; Dobbelsteen et al., 2002; Bonesronning, 2003; Leuven et al., 2008; Hojo, 2013; Akabayashi and Nakamura, 2014; Angrist et al., 2019), long-term outcomes (e.g., Krueger and Whitmore,

[4] Our estimation results can contribute to recent research analyzing social distancing behaviors under the COVID-19 pandemic in Japan. For example, in Japan, Sasaki et al. (2020) analyze the effect of nudge messages on contact and infection prevention behaviors and life satisfaction, Shoji et al. (2020) estimate the association between numbers of new COVID-19 cases in a local area and social distancing behaviors such as frequency of face-to-face conversation of people residing in the local area, Yamamura and Tsutsui (2020) estimate the effect of a declaration of a state of emergency on infection prevention behaviors and mental health, and Watanabe and Yabu (2020) estimate the effect of the declaration of the state of emergency on stay-at-home measures, using smartphone location data. While behavioral changes are observed in the aforesaid studies, it is still unclear if the changes in social distancing behaviors could reduce the infections. Since our results suggest that the increase in physical distance could prevent a spread of infectious diseases in a space, the behavioral changes observed under the current pandemic could contribute to preventing the spread of infection.

2001; Chetty et al., 2011; Fredriksson et al., 2013; Leuven and Løkken, 2020), parental responses (Fredriksson et al., 2016), and manipulation of students' test scores by teachers (Angrist et al., 2017), less attention has been paid to protection of student health.[5] Therefore, we will focus on students' health outcomes, which could provide new insight to class size effect studies. In addition, according to our results, we could also say that class size reduction may positively affect students' achievements because the reduction protects students' health conditions from infectious diseases, in other words, provides an improvement of study environments for students. Therefore, our results could explain a mechanism behind class size effects on academic achievements and future outcomes found in the previous studies.

The remainder of the paper is organized as follows: section 2 explains the institutional background, and section 3 discusses the data and descriptive statistics. Section 4 describes the estimation model, and section 5 discusses the estimation results. Section 6 provides some additional remarks, and section 7 concludes this paper, with suggestions for further research.

2 Institutional Background

In this section, we briefly summarize the institutional settings of education in Japan related to: 1) judgment of class closure; 2) regulation of class size; 3) surface area of classroom; and 4) other features of Japanese classes related to flu spread in classrooms.

Class closures due to influenza are common in Japan. The majority of these closures are reactive closures, as defined in Cauchemez et al. (2009): closure of a school/class when many children, staff, or both are experiencing illness. While school closure is expected to be a non-pharmaceutical intervention to mitigate local flu epidemic in general, reactive closures are considered in Japan as a measure to allow absent students to catch up with their peers more easily once they are healthy again (Ministry of Health, Labour and Welfare of Japan, 2009). One reason why reactive school closures are common in Japanese society may be general support for this equity concern. In Japan, the School Health and Safety Act gives school administrators discretion to shut down schools, grades, and classes under their jurisdiction to prevent expansion of viral infections and to guarantee learning opportunities for absentees due to flu. In the case of public primary and middle schools, education boards of local municipalities, and not school principals, decide whether or not to shut them down. The national government does not provide explicit criterion for judgment of the shutdown. In some cases, prefectural or municipal education boards set the criterion for judgment for their public

[5] Jakobsson et al. (2013) analyzed the effects of class size on adolescents' mental health problems and well-being using a Swedish dataset and concluded that the results cannot show that class size does not affect mental health problems and well-being.

schools. The criteria vary across prefectures and municipalities, but in many cases education boards decide to close classes, grades, or schools when the rate of absentees reaches 20%. In Japan, flu is a major cause of class shutdowns. Since flu infection expands in the winter season, most class closures are observed in this season. In 2018-2019 in Tokyo, the number of flu infections increased from December, peaked in January, and got closer to zero in February, and class closure was mainly observed in January and February.[6]

Public elementary (grades 1 to 6) and middle (grades 7 to 9) schools in Japan have an upper limit of class size set by the Act on Standards for Class Formation and Fixed Number of School Personnel of Public Compulsory Education Schools. The law allows education boards of the governments to set an original upper limit to class size as long as the limit is below the national standard. Public schools in City X have an upper limit of 35 students for 1st, 2nd, and 7th grades and 40 students for the other grades (3rd, 4th, 5th, 6th, 8th, and 9th grades). These upper limits are considered exogenous for City X because they are based on the classroom arrangement standards of the education board of the prefecture in which City X is situated.[7][8] In addition, students experience both class reshuffling and change in the upper limit of class sizes simultaneously, because in City X, it is common for classes to be reshuffled when students go from 2nd to 3rd grade and when students get promoted from elementary to middle school.[9]

Next, we explain the surface area standard for classroom in Japan. The standard for surface area in classrooms under the Standard Design of Reinforced Concrete School Buildings of 1950 is 63 m^2. According to Mori (2019), surface area in classrooms is distributed around the standard, 63 m^2, in both elementary and middle schools: the average value of surface areas is 64.80 for elementary schools and 65.05 for middle schools, and the median values are 64 and 65, respectively.[10] Since most classrooms are constructed in accordance with the standard, there is less variation in the area of classrooms than in the number of students in a classroom. Therefore, the number of students in the classroom and change in it largely determines the students' potential for physical distancing in

[6] http://idsc.tokyo-eiken.go.jp/diseases/flu/flu2018/

[7] In Japan, the upper limit of class size for each grade in elementary and middle school is determined by education boards of prefectures based on national standards. The education board of a municipality follows the standards determined by the prefecture in which the municipality belongs.

[8] In Japanese elementary and middle schools, the upper limit of class sizes had been 40 students until 2010; this was lowered nationwide to 35 only for 1st graders in 2011, because lowering the limit for all grades would cost a lot. The 1st graders need intensive care from teachers, effected by reducing class sizes, because 1st graders experience dramatic changes in their surroundings by entering schools. In addition, in some financially rich prefectures, including the prefecture to which City X belongs, the upper limit of 35 is applied not only to 1st graders but also for 2nd graders and 7th graders. The 2nd graders are still at a stage of adjusting to dramatic changes, and the 7th graders experience dramatic changes in their surroundings again upon entering middle school.

[9] We discuss the class reshuffle in Appendix A.1.

[10] Distribution of surface areas of classrooms is presented on p. 87 of Mori (2019).

the classroom. If surface area in a classroom is 63 m^2, the area per person is 1.54 m^2 for classes with a teacher and 40 students, that is, class size 40, and 2.25 m^2 for class size 27. Increase in classroom area per person should expand social distance among people in the classroom.

Finally, we explain other settings in schools in Japan related to flu spread in classrooms. In most Japanese classrooms, students have their own desks, and desks are arranged to face the front of the classroom. Since students have their own desks, it is not difficult to arrange desks depending on the situation. For example, students can arrange desks to maintain their physical distance and prevent infections if they have enough space. In Japanese public schools, natural ventilation is a common way to air out homeroom classes.[11] For natural ventilation, the guidelines of facility maintenance for elementary schools[12] and for middle schools[13] recommend to construct doors and windows with proper layout, size and form to ventilate effectively. The natural ventilation could be implemented even in the winter season, when the number of flu infections increases, because most of the public elementary schools in an area, including the Tokyo Metropolitan Area, have heating systems (Yoshino et al., 2009). For preventing infection by seasonal flu, handwashing and wearing facial masks are recommended in a handbook by the Japanese Society of School Health.[14]

3 Data

This paper utilizes the school administrative data collected by the Education Board of City X. City X is a large municipality with more than 300,000 households and a population of more than 600 thousand people in 2015. In 2015, City X had about 70 public elementary schools with about 1000 classes and about 40 public middle schools with about 400 classes. The data cover various information related to educational administration, such as the list of students in classrooms and the instance of class shutdowns, for all public elementary and middle schools operated by City X. Since, as explained, the education boards of local governments make the final decision on class closure in Japanese public schools, the Education Board of City X keeps the records on school shutdown in schools operated by them. The shutdown data include two types of closures: class closures and grade closures, where one class (or grade) would be kept home but another allowed to go to school. In this paper, we utilize both types of closure and hereafter, for simplicity, will call both class closure. While the data contains students' information for a long period, information about class

[11] About 31 % of the public elementary schools in an area including the Tokyo Metropolitan Area had ventilation systems in homeroom classes in 2005 (Yoshino et al., 2009).

[12] https://www.mext.go.jp/content/1414564_001.pdf (accessed on July 21, 2021) (Japanese only)

[13] https://www.mext.go.jp/content/1414564_002.pdf (accessed on July 21, 2021) (Japanese only)

[14] https://www.gakkohoken.jp/book/ebook/ebook_H290100/data/199/src/H290100.pdf?d=1626864804639 (accessed on July 21, 2021)(Japanese only)

closure due to flu is only available for three years, from 2015-2017. Using the data, we construct three-year class-level data, which include classes' characteristics and incidence of class closure. We exclude classes with less than 17 students and classes in grades with less than 30 students, as there are not many classes or grades with very few students. After the sample restriction, 4271 observations in public elementary and middle schools are available for analysis.

[Table 1 about here.]

Table 1 summarizes the sample average and standard deviation for variables. Column (1) shows statistics for entire classes, and Columns (2)-(5) are those for grade categories. According to Column (1), among the entire sample, about 17.3% of classes have 27 students or less and average class size is about 31.5. The higher the grade, the larger the class sizes, but the increases are not substantial (Columns (2)-(5)). The proportion of class closure due to flu among the entire sample is about 8.6% (Column (1)) and decreases as the grade goes up (Columns (2)-(5)).[15]

[Figure 1 about here.]

[Figure 2 about here.]

Figure 1 shows the number of closed classes due to a flu epidemic by month. In public schools in City X, the peak of the flu epidemic is observed between December and February, the winter season in Japan. All three years have same tendency. Figure 2 shows the distribution of the absentee rate in classes just before class closure.[16] According to Figure 2, among closed classes, the minimum value of the absentee ratio is about 10%. However, this does not necessarily imply that an absentee ratio of 10% is a criterion for class closure, because the data on the absentee ratio are available only for the closed classes. Most of the closed classes have an absentee ratio from 25% to 40%, with mean value of 34.0% and median is 33.3%.[17] One explanation of the variation of the absentee ratio is that homeroom teachers observe the state of flu spreads in classrooms in other ways in addition to the absentee ratio, such as how many students are coughing in class, and report the situation to school principals. In this case, it is possible that class closures capture the flu epidemic

[15] Since some classes experience multiple class closures in a year, the class closure dummy takes value one if a class experiences at least one class closure in a school year. The ratio of classes closed due to seasonal flu twice in a year to all the classes that experience class closure in the year is about 5%.

[16] This figure excludes the case of grade closure, because it is difficult to identify the number of absentees in each class in such a situation.

[17] After we control for school, year, and grade fixed effects, the standard deviation of the absentee ratio is about 26.4% smaller than that for the raw one, while there still remains variation in the absentee ratio. The fixed effects could explain about 46% of the raw absentee ratio. Appendix A.1 discusses this point further.

in classrooms more accurately than the absentee ratio. In addition, if teachers in smaller classes can observe students' health condition more accurately, the smaller classes are more likely to be closed, and our estimation results may underestimate the actual impact of class size on within-class transmission of flu. Our estimates should still be conservative even if this is the case, however.

Finally, we show a relationship between class size and absentee ratio before class closure to discuss the validity of class closures as a proxy flu epidemic in classes. Class closure is no longer a good proxy for a flu epidemic in classes if the education board more rapidly selects class closure in larger classes to prevent a flu epidemic in entire schools even when the proportion of infected students in the classes is low. If the education board more rapidly decides on class closure for large classes regardless of the intensity of virus spread, there should be a negative relationship between class size and the absentee ratio in classrooms just before class closure. We confirm whether there exists a negative relationship using a class-closure-case-level dataset with class characteristics because, unfortunately, the absentee ratio data only cover classes actually closed due to a flu epidemic.[18] Using the dataset, a regression model of the absentee rate on the class size variable is developed, and the set of control variables is estimated.[19]

[Table 2 about here.]

Table 2 summarizes the estimation results. The analysis sample consists of all cases of class closure in both elementary and middle schools. After controlling for observable characteristics, the coefficient of class size is negative but statistically insignificant (Column (1)). Compared to the overall mean, a one-unit increase in class size decreases the absentee ratio by 0.7%. The magnitude for the absentee ratio is much smaller than the magnitude of effects of class size reduction on class closures discussed in Section 5. This tendency is robust against the definition of the class size variable (Column (2)). Therefore, the possibility that the education board more rapidly decides on class closure for larger classes regardless of the intensity of virus spread should not greatly contribute to the interpretation of the results.

[18] Since some classes experienced closure twice, we do not use a class-level dataset but instead a case-level dataset, to increase the sample size. For simplicity, we exclude the case of grade closure, because it is difficult to identify the number of absentees in each class.

[19] We utilize number of students in a grade in a school, squared number of students in a grade in a school, girl ratio, grade FEs, and year FEs as the control variables.

4 Estimation Model

The estimation equation is as follows:

$$Closure_{jsgt} = \alpha + \beta ClassSize_{jsgt} + x'_{jsgt}\delta + \eta_t + \xi_s + \lambda_g + u_{jsgt} \tag{1}$$

where j, s, g, and t are indices of class, school, grade, and year. The dependent variable $Closure_{jsgt}$ takes one if the class is closed due to a flu epidemic. We utilize closure as a proxy for a flu epidemic in classrooms because it is a useful assessment measure of the trend of epidemic phenomena (Suzue et al., 2012). Although one could argue that the absence rate in a class is a better outcome variable than class closure, we cannot use it in the analysis due to the lack of data availability: the data for absence rate are available only for classes actually closed due to a flu epidemic. However, class closure is informative about a flu epidemic in our setting because closing a class is considered by the education board of the municipality when the absence rate exceeds a common threshold in the municipality (called reactive closures in Cauchemez et al., 2009), and thus it is natural to think that the absence rate of classes without closure is lower on average than those with closure.[20]

The variable $ClassSize_{jsgt}$ represents class size. In this paper, we use two definitions of the class size variable: the linear term of class size and a dummy variable that takes one if the class size is less than or equal to 27. If a classroom is 63 m^2 in size, a class size of 27 is the threshold where the area per person in the classroom becomes over 2.25 m^2 when the class size is reduced.[21] Being within 1.5 m of an infected person increases the risk of droplet infection[22] , and class size of 27 could provide an area of square 1.5 m on a side (2.25 m^2) for each person: the people in the classroom can maintain a physical distance of 1.5 m. Therefore, the dummy variable could be interpreted as an indicator of whether students have enough physical distance to prevent droplet infection of flu. The vector x_{jsgt} is a set of control variables that includes the linear and squared

[20] One of the ideal outcome variables to examine our hypothesis is a class's absentee ratio due to flu in the flu season, December to March, while we utilize the class closures dummy as an outcome variable because of data limitations. The dependent variable, the class closures dummy, may have measurement errors, and if the measurement errors are correlated with class sizes, the coefficient of class size is no longer consistently estimated. For example, the education board may more rapidly select class closure in larger classes to prevent a flu epidemic in entire schools even when the proportion of infected students in the classes is low. In this case, measurement error and class size are correlated, and the effect of class size reduction on class closures is not consistently estimated. Fortunately, Table 2 does not support the above possibility, and we can thus conclude that class closures are not a bad proxy for a flu epidemic.

[21] The area per person is 2.17 m^2 for classes with a teacher and 28 students.

[22] According to a guideline for influenza by the Japanese government, the relatively large droplets exhaled by a person infected flu can directly enter the respiratory organs of surrounding people at a distance of 1 to 1.5 m and cause viral infection. Please see a footnote on p. 4 in `https://www.mhlw.go.jp/bunya/kenkou/kekkaku-kansenshou01/dl/tebiki25.pdf#page=4` (accessed on June 23, 2020). Liu et al. (2017) found that the distance of 1.5 m is a threshold substantially increasing airborne exposure to droplets exhaled by the source.

terms of the number of enrollees in a grade in the school and the ratio of girls in the class. The parameters η_t, ξ_s, and λ_g capture the year, school, and grade fixed effects (FEs). Year FEs could capture the status of a flu epidemic outside of schools, which is one determinant of a flu epidemic in classrooms and may be correlated with class size. Public schools in City X are close to each other: City X has about 2 public schools per square kilometer[23] . Flu spread outside of school may not differ substantially within City X. u_{jsgt} is an unobserved error term. In Equation (1), β is the parameter of interest in this paper.

Identifying the causal effect of class size is challenging when the class size is endogenous. Schools that have students who need more intensive instruction from teachers, for example, students with physical/mental health problems, disability, or problem behaviors such as hyperactivity disorder, may utilize a small class. These students' characteristics are likely to affect class closure because students with health problems may be more susceptible to the virus and it may be difficult to keep up social distancing particularly among such students. In this case, the effect is underestimated in the absolute value. This paper utilizes an instrumental variable approach using the upper limit of class size.

Angrist and Lavy (1999) utilized the fact that class size changes discontinuously when the number of enrollees in a grade increases around the upper limit of class size. For example, if both the upper limit and the number of enrollees are 40, a class of 40 students is organized in this grade, but if the number of enrollees increases to 41, the class is divided into two classes: a class of 20 students and a class of 21 students, because a class size of 41 exceeds the upper limit. The identification strategy relies on this discontinuous change due to the administrative rule called the Maimonides' rule. Since, as explained in Section 2, public schools in Japan follow similar class organization rules, we utilize this rule to identify the causal effect of class size. Following Angrist and Lavy (1999), we predict class size by the Maimonides' rule as follows:

$$Msize_{jsgt} = \frac{SchoolSize_{sgt}}{int(\frac{SchoolSize_{sgt}-1}{L_{sgt}} + 1)} \tag{2}$$

where $SchoolSize_{sgt}$ is the number of enrollees in a grade in a school and L is the upper limit of class size. As explained, City X sets the upper limit in public schools as 35 for 1st, 2nd, and 7th grades, and 40 for other grades.

[Figure 3 about here.]

[23] The area of City X is about $50km^2$, and the number of public schools as of 2015 is 100.

Figure 3 shows the actual class sizes and the class size predicted by the Maimonides' rule. Most of the actual class size overlap the predicted class sizes.

We estimate Equation (1) by 2-Stage Least Squares (2SLS) using the predicted class sizes as the instrumental variable. The first stage equation is as follows:

$$ClassSize_{jsgt} = \pi + \rho Msize_{jsgt} + x'_{jsgt}\gamma + \phi_t + \theta_s + \mu_g + v_{jgt}. \tag{3}$$

We use the same control variables as Equation (1). The parameters ϕ_t, θ_s, and μ_g respectively capture the year, school, and grade FEs, and the parameter v_{jsgt} is an unobserved error term. Empirical works with instrumental variable strategies often encounter weak instruments. We will investigate the possibility of weak instruments using first-stage F-statistics and the rule-of-thumb value of 10.

An identification assumption, absent the manipulation of enrollment by parents, should be satisfied to allow the instrumental variable estimation to be employed. Since City X has introduced a school choice program for public schools, parents could partially choose a school for their children in our sample period (see below). If parents want their children to enroll in smaller classes, in which the children may receive more intensive instruction and get higher achievement, and if the parents then choose a school by predicting class size with the Maimonides' rule, the identification assumption is violated. However, the influence of manipulation on estimation results should be little, for the following reasons. First, City X assigns children to public schools based on the children's residential addresses, like other Japanese municipalities, and students are ensured enrollment in their assigned school if they choose it. If parents want their children to enroll in a school other than the assigned school, they can apply to the school choice program. Since City X sets upper caps of the number of enrollees in the school in advance depending on the number of residents around the school, children are not always able to choose a school, however. Therefore, there are uncertainties in school choice, and it is difficult to manipulate enrollment perfectly.[24] Second, in cities of Tokyo Metropolitan Area introducing school choice programs, students apply the programs mostly because of reasons not related to academic achievement, for example, closeness between houses and schools and friends plan to enroll the school.[25] Therefore, it is unlikely that the school

[24] Parents also can choose a school by moving to the area which the school covers. However, it is very costly for households to move. Hojo (2013) and Akabayashi and Nakamura (2014), which analyzed class size effects in Japan, argued that moving for school enrollment is costly and does not occur much.

[25] According to Yasui (2012), in a city, students who enroll in schools other than the assigned school choose the school mostly because their friends plan to enroll there. In other cities, the closeness between houses and schools is the most common reason why students choose the school.
(`http://www.city.sumida.lg.jp/kosodate_kyouiku/kyouiku/school/nyuuen_nyuugaku/annke-tokekka.files/ANKEITOCHOUSAKEKKAGAIYOU.pdf`, accessed on June 19, 2020)

choice program is being used to put children in small classes. Additionally, we put school FEs in the estimation model to control for the school's unobserved characteristics.

5 Results

[Table 3 about here.]

Table 3 shows the estimation results for the effects of class size on class closure. Columns (1), (2), and (3) are the results using the linear term of class size, and Columns (4), (5), and (6) are those using the class size dummy, which takes one if the class size is less than or equal to 27. We report the results using Ordinary Least Squares (OLS) (Columns (1) and (4)), those using 2SLS (Columns (2) and (5)), and those using 2SLS for classes in the schools whose enrollments are between the cutoff values plus 6 and minus 6 (Columns (3) and (6)). In Table 3, standard errors robust against school-level clustering are reported in parentheses.

According to Table 3, by OLS estimation, the estimate of class size ("class size") is 0.0031, statistically significant at the 10% level (Column (1)). By comparing the estimate with the overall mean, 0.086, we see that a one-unit decrease in class size is associated with about a 3.6% decrease in the probability of class closure. Since, as mentioned, there is the possibility that the OLS estimate suffers from endogeneity bias, this causal interpretation requires a caution.

To control for endogeneity bias, we also estimate Equation (1) using 2SLS. According to the estimation result, the estimate of class size is 0.0046, statistically significant at 5% (Column (2)). The F-statistic for the first stage is about 1074.41, over the rule-of-thumb value of 10, which suggests that the instrumental variable in the first stage works well. By reducing one unit of class size, compared with the overall mean, the probability of class closure is thus decreased by 5.3%. The magnitude of the 2SLS estimate is about 48.4% larger than that of the OLS estimate. Therefore, there seems to be a downward bias in absolute value in the OLS estimate. When we restrict the sample to classes in the schools whose enrollments are in between the cutoff values plus 6 and minus 6, the estimate by 2SLS is 0.0051 and statistically significant at the 10% level (Column (3)). Compared with the overall mean, a one-unit reduction in class size decreases the probability of closure by 5.2%, which is almost the same level as the result of standard 2SLS, while the magnitude of the estimate is slightly larger than that of the standard 2SLS estimate (0.046 vs 0.0051). Therefore, the restriction of the sample around the discontinuity does not affect the estimation results. On the other hand, compared with 2SLS, the standard error of "2SLS±6" is higher, and thus, the significance level

(`https://www.city.minato.tokyo.jp/gakkouuneishien/kodomo/gakko/tetsuzuki/tennyugaku/sentaku/enquete/documents/29anke.pdf`, accessed on June 19, 2020) goes down. In this specification, the F-statistic is 304.08, over the rule-of-thumb value of 10. The results using 2SLS suggest that after we control for the endogeneity bias using the Maimonides' rule, one-unit reduction in class size decreases the probability of class closure by about 5.2%-5.3%.

The estimation results are robust when we utilize the other definition of the class size variable. The estimate of the class size dummy using 2SLS ("class size $\leq$ 27") is -0.0757, statistically significant at 5% (Column (5)), while the OLS estimate is -0.0281 and is statistically significant at 10% (Column (4)). By reduction of the class size from over 27 to 27 or below, compared with the mean in classes with over 27 students, 0.087, the probability of class closure due to a flu epidemic is decreased by 86.6%. The size of the effect is about -87.1%when we use classes in schools whose enrollments are in between the cutoff values plus 6 and minus 6 (Column (6)). Therefore, we can reduce class closure substantially if we reduce class size to less than or equal to 27 (86.6%-87.1%).

[Table 4 about here.]

Next, we implement a subgroup analysis by grade in school. Table 4 shows the estimation results using the linear term of class size by grade. In this analysis, we divide the classes into three categories by grade: "1st, 2nd, and 3rd," "4th, 5th, and 6th," and "7th and 8th." The categories "1st, 2nd, and 3rd" and "4th, 5th, and 6th" correspond to classes in elementary schools and "7th and 8th" to those in middle schools.[26] We estimate only two types of models, "OLS" and "2SLS," because the estimate of "2SLS" and that of "2SLS ± 6" are not different and there is less variation when we utilize school FEs and restrict the sample.

According to Table 4, the higher the grades, the larger the magnitude of the estimates. Among "4th, 5th, and 6th," the 2SLS estimate is 0.0061 and statistically significant; compared to the overall mean (0.074), a one-unit reduction of class size decreases the probability of class closure by 8.3% (Column (4)). In the case of "7th and 8th," the 2SLS estimate is 0.0134, statistically significant, and about double the estimate for "4th, 5th, and 6th" (Column (6)). Compared to the overall mean (0.076), the probability of closure is reduced by 17.7% by a one-unit decrease in class sizes. The estimate for "1st, 2nd, and 3rd" is about one-fourth that for "4th, 5th, and 6th," and statistically insignificant.

To sum up, we found that reduction in class size decreases the incidence of class closure and that the effect is strong for the higher grades. These results suggest that the class size reduction

[26] We exclude the 9th grade from the middle school category, because when we include 9th grade classes in this category the estimation results become noisy. In Japan, 9th grade students take a high school entrance exam mainly between January and March and the peak of a flu epidemic overlaps with these months. Therefore, 9th grade students are likely to get a flu vaccination because they do not want to miss their big exam. The data support this possibility: the rate of class closure in 9th grade is about 3%, one-fourth of the rate among 1st to 3rd grades. By means of these aspects, the results could become noisy.

mitigates the epidemic of flu virus in the classroom among older students.

6 Discussion

In this section, we interpret the effects and give policy implications for schools reopening during the COVID-19 crisis.

6.1 Interpretation of Effects of Class Size on Class Closure

In this subsection, we discuss 1) possible mechanisms behind the effects of class size on class closures and 2) the effect of preventing class closures by class size reduction on students' human capital accumulation.

One possible interpretation of the mechanism behind the effects of class sizes on class closures is that the education board more rapidly select class closure in larger classes to prevent a flu epidemic, even when the proportion of infected students is low. As mentioned in Section 2, the national government in Japan does not provide explicit criteria for class closure, and local education boards can make the decision on class closure flexibly. In such a context, interpretation of the class size effects is complicated. In this case, the estimation results do not necessarily support the argument that class size reduction can mitigate a flu epidemic in classrooms. According to discussions in Sections 3 and 4, we can conclude that the possibility that the education board more rapidly decide on class closure for larger classes regardless of the intensity of virus spread should not greatly contribute to the interpretation of the results.

[Figure 4 about here.]

The second possibility is that the larger class size, the higher the probability that the class has at least one infected student, which could be a driver of a flu epidemic in the class. In this case, the positive relation between class size and class closure should be observed even if the probability of within-class transmission is not different by class sizes. We discuss this possibility using Figure 4, showing the results of a simulation of the relationship between class size and the probability that classes have at least one infected student. We assume that the probability that a student gets infected is independent and identically distributed, and utilize three values, 0.075, 0.1 and 0.125, as the probability that a student gets infected.[27] Using the three values, we calculate the probability that

[27] According to a report by the Japanese Ministry of Health, Labour and Welfare, estimated numbers of people infected by seasonal flu are about 9.91 million for the 2015 season, about 10.46 million for the 2016 season, and about 14.58 million for the 2017 season.(https://www.mhlw.go.jp/content/000509899.pdf, accessed on July

classes have at least one infected student for each class size.According to Figure 4, the larger class size is, the higher the probability that classes have at least one infected student, and the probability reaches 90% when the class size is 30 in all the three scenarios. The probability that classes have at least one infected student decreases by about 1.4%-5.5% when the class size changes from 40 to 30. According to the 2SLS model in Table 3, a ten-unit decrease in class size prevents about 53% of class closures compared with the overall mean (Column (2) in Table 3), and the magnitude is much larger than the percentage change in simulated probability when the class size changes from 40 to 30. Therefore, we can conclude that the second possibility does not greatly contribute to the interpretation of the results.

Third, it is possible that as class size decreases, the spread of a flu epidemic slows. This may be because of the increase in social distancing in classrooms and/or the increase in time teachers can spend with each student. Increasing physical distance from others is one key strategy to prevent spread of viruses. As explained, in Japan, since most classrooms have almost the same surface area, class size (student numbers) determines physical distance for each student. The smaller the class size, the larger students' physical distance from others. If a classroom has a surface area of 63 m^2, the reduction of class size from 40 to 27 increases the area per student by about 46.1%: from 1.54 to 2.25 m^2. Students can then maintain a physical distance of 1.5 m, which is the threshold reducing the risk of infection due to relatively large droplets exhaled by the person when class size is decreased to 27. According to the estimation results, among classes with 27 or fewer students, the probability of class closure substantially drops (86.6%-87.1%) compared to the classes with over 27 students. This may be because these students can maintain the ideal level of distance from other students in the classroom. Additionally, when we use a cubic function of class size and estimate the class size effects, the estimation result shows that the marginal effects are statistically significant at 10 % between class sizes of 27 and 34. The estimation result implies that if students do not have a certain level of physical distance to prevent exposure to droplets, class size reductions are not effective to prevent flu epidemics in classrooms. The result also implies that once students get enough physical distance, class size reduction is no longer effective to decrease the probability of flu infection. [28] Therefore, it is possible that the increase in physical distance for each student by the reduction of class size can help prevent a flu epidemic in classrooms.[29] It is also possible that the

19, 2021) Population estimates for April 1 are 12.691 million in 2015, 12.698 million in 2016, and 12.679 million in 2017. By dividing the estimated number of people infected by seasonal flu by the population estimate, we can calculate a probability that a person gets infected as 7.81%, 8.24% and 11.5% for 2015, 2016 and 2017, respectively. The three values, 0.075, 0.1 and 0.125, cover the calculated probabilities for 2015 to 2017.

[28] Appendix A.3 discusses more details of the estimation results with the cubic function.

[29] If the prevention of droplet infection reduces the incidence of epidemics in classrooms, other ways to prevent droplet infection than the class size reduction, such as wearing face masks in classrooms and setting up partitioning screens between students, may also help to reduce epidemic in classrooms.

reduction in class size gives teachers more time to spend with each student and that this intensive instruction prevents a flu epidemic. However, since a previous study found no class-size effects on health conditions such as mental health problems and well-being among Swedish 9th graders (Jakobsson et al., 2013), it is likely to be more effective to focus on increasing physical distance by reducing class size than on other possibilities, like increasing teachers' time spent with each student in the case of health outcomes. The social distancing hypothesis could provide an explanation for the heterogeneous effects by grade in school. According to a report by the Ministry of Education, Culture, Sports, Science and Technology in 2009, 1st to 3rd graders are still at the stage of developing their skills to understand and decide about good and evil by following what parents and teachers say.[30] Therefore, class size reduction does not work well for prevention of a flu epidemic among younger students because it is possible that 1st to 3rd graders are not better at following other protective measures on flu spread in schools, such as wearing facial masks and washing their hands carefully, than older graders, even though they have enough physical distancing.[31]

Next, we discuss whether the prevention of class closures by class size reductions affects students' human capital accumulation. According to Bessho et al. (2021), analyzing effects of class closures on students' achievements using the data from City X, experiencing class closures due to seasonal flu decreases mathematics test scores by 8.68% of a standard deviation among elementary school boys from disadvantaged households. Using the estimated damage by Bessho et al. (2021) and the estimated effects of class size on class closures among 4th to 6th graders, 8.3% ("%Δ from overall mean" in Column (4) in Table 4), we can calculate that a ten-unit reduction of class size increases mathematics test scores among elementary school boys from disadvantaged households by 7.1% of a standard deviation. For example, the magnitude is comparable with an effect of an additional schools' instructional hour per week on PISA scores, 5.8% of a standard deviation, as estimated by Lavy (2015). Therefore, social distancing created by class size reductions affects not only flu epidemic prevention but also consequent student achievements.

To sum up, social distancing due to the class size reduction is one possible account of the positive effects of class size on the probability of class closure due to flu, and could affect students' consequent achievements. In addition, since class or school closures force working parents to reduce their working hours, and have economic costs through such as the reduced working hours according

[30] https://www.mext.go.jp/b_menu/shingi/chousa/shotou/053/gaiyou/attach/1283165.htm (accessed on June 19, 2021)(Japanese only)

[31] The upper limit of class size is another possible explanation for the heterogeneity. It is possible that we do not obtain significant class size effect for 1st to 3rd graders because, according to Table 1, they have smaller class sizes than older graders with enough physical distancing to prevent transmission of the virus in all classes. However, this explanation contradicts the summary statistics showing that 1st to 3rd graders are more likely to experience class closure. Therefore, we would like to emphasize the first explanation.

to Viner et al. (2020), it is possible that the prevention of spread of infection by reduced class sizes could save on these economic costs. We would expect this social distancing to be effective not only against flu but also against other viruses like COVID-19. In the next subsection, we would like to discuss the policy implications of our study for the current COVID-19 pandemic.

6.2 Policy Implications for Schools During the COVID-19 Crisis

Currently, in many countries, schools are shut down because of the COVID-19 pandemic. Since the reduction of school instruction time negatively affects student achievement and expands the gap in achievement by socioeconomic situations, school reopening is an important policy issue that needs to be dealt with promptly. Social distancing for students should have a key role when schools restart, and reduction of class size is a way to create the needed physical distance. As explained above, according to our estimation results, class size reduction can prevent a flu epidemic in classrooms. In this subsection, we would like to discuss class size policy when schools are reopened during the COVID-19 crisis using our estimation results for the effects of class size on class closure due to flu.

Creating the physical distance for each student is a way to protect students from exposure to droplets exhaled by an infected student. In terms of reducing the exposure, increases in physical distance by class size reductions should have same effects for both flu and COVID-19. According to Liu et al. (2017), the exposure to droplets exhaled by a source substantially increases within the distance of 1.5 m from the source. Actually, the distance of 1.5 m is utilized as a guideline of "social distancing" for the current COVID-19 crisis in some countries such as Australia, Belgium, Germany, and Italy.[32] Therefore, we consider that the class size reduction is an effective way to protect students from the exposure to droplets from other students not only for flu but also for COVID-19.

On the other hand, however, the heterogeneity of infectivity between flu and COVID-19 may make a difference in the effectiveness of the class size reduction even if we protect students from the heavy exposure to droplets from the infected student. According to previous studies, COVID-19 is likely more infectious than flu among the entire population,[33] although we need more discussion of the case of children. For COVID-19, a meta-analysis found preliminary evidence that children have

[32] `https://www.bbc.com/news/science-environment-52522460` (accessed on June 23, 2020).

[33] The basic reproduction number (R_0), which is a measure of infectivity and is defined as "the average number of new infections that one case generates, in an entirely susceptible population, during the time they are infectious" (Coburn et al., 2009, p. 2), of the novel coronavirus is estimated to be higher than the estimated R_0 of flu. A recent review article reported that the estimated R_0 of the novel coronavirus has a mean of 3.28 and median of 2.79 (Liu et al., 2020), while the estimated R_0 ranges from 0.9 to 2.1 with mean of 1.3 for seasonal flu, from 1.4 to 2.8 for the 1918-1919 pandemic strain, and from 1.4 to 1.6 for novel influenza (Coburn et al., 2009). Compared with the mean R_0 of seasonal flu, that of the novel coronavirus is about 2.5 times higher.

lower susceptibility to COVID-19 than adults (Viner et al., 2021), and according to the estimates of Dattner et al. (2021), the susceptibility of children is 43% of that of adults and the infectivity of children is 63% of that of adults. In contrast, for flu, according to a meta-analysis conducted in Tokars et al. (2018), children are more likely to be infected than adults: the incidence rate of flu among children is 8.7% while that among adults is 5.1%. Using the values, we can assume that among children, infectivity of COVID-19 is comparable to that of flu.[34] In the case that the infectivity of COVID-19 is comparable with that of flu, our estimation results can be applicable to the COVID-19 pandemic. Class size reductions could reduce within-class transmissions of COVID-19. Additionally, if COVID-19 is less infectious than flu among school-aged children, our estimated effects are lower bounds in terms of absolute value of the effects for COVID-19. In that case, our estimation result should be a conservative evaluation of effects of class size reduction for COVID-19. Further analyses of the effect of social distancing on COVID-19 infection, such as quantitative analysis using mathematical models, can give us more insight for discussing whether or not class size reduction is effective for COVID-19.

Current studies report long-term health consequences of COVID-19, so-called long COVID, among children(e.g., Buonsenso et al., 2021a,b; Brackel et al., 2021; Ludvigsson, 2021; Say et al., 2021). For example, Buonsenso et al. (2021a) conducted follow-up surveys for children infected with COVID-19 and found that among children surveyed 120 days after the diagnosis, about 31% had 1 to 2 symptoms, and about 20% had 3 or more symptoms. According to Brackel et al. (2021), 89 children in Netherlands are suspected to have prognostic symptoms, and about 36% of them have experienced severe limitations in daily life. Since previous studies have found a positive relationship between childhood health and future outcomes (Currie, 2009), these long-term health consequences of COVID-19 may affect children's life-cycles in the long-run. In the case of COVID-19, creating social distancing in classrooms by class size reductions would be a way to protect students from not only short-run but also long-run damage.

7 Conclusion

This paper analyzes the effects of class size reduction on class closure due to a flu epidemic using administrative data from City X in Tokyo Metropolitan Area, and the instrumental variable strategy

[34] Suppose that an adult infected with COVID-19 generates an additional 3.28 new infections and that compared with adults, children generates additional 63% of the number of new infections among adults, that is, 2.0664 new infections. On the one hand, suppose that an adult infected with COVID-19 generates an additional 1.3 new infections and that compared with adults, children generates an additional $1.7 (\approx 8.7/5.1)$ times the number of new infections among adults, that is, 2.21 new infections. Then, the number of new infections by a child infected with COVID-19 is comparable with that for flu.

with the Maimonides' rule. According to the estimation results, one-unit reduction in class size decreases the incidence of class closure due to flu by about 5.2%-5.3%, and forming small classes with 27 students reduces class closure by about 90%. If a classroom has 63 m^2 of area, a standard for classroom area in Japan, by reducing the class size to below 27, students can maintain 1.5 meters' physical distance from others, which is the threshold reducing the risk of infection due to relatively large droplets exhaled by the person. Additionally, when we use a cubic function for class size and estimate class size effects, the estimation result shows that the marginal effects of class sizes are statistically significant between class size of 27 and 34, implying that once students get a certain level of physical distance, class size reduction is no longer effective to further decrease the probability of flu infection. Thus, taken as a whole, the results seem to show that class size reduction increases physical distance between students and consequently prevents a flu epidemic in classrooms. The results also show that the class size reduction is effective only among older students. Our results on class-size effects could be applicable to COVID-19, but we need to proceed carefully. For safety of students and teachers, increasing students' physical distancing by class size reduction should be implemented in schools during the COVID-19 pandemic. Spread of viruses affects not only students' health but also their academic achievement. Decrease in school instruction time as a result of class closures due to virus spread is likely to affect student achievement and expand socioeconomic gaps in achievement.

Before concluding, we will mention two limitations of this paper that should be addressed in future work. First, the decrease in probability of class closures by class size reduction does not necessarily imply a decrease in flu infection in classrooms due to social distancing; there may be other explanations (though we eliminate one critical explanation in Section 6). For further analysis, we need more detailed datasets, for example, data individually tracking students' absence and reasons for it allows us to better analyze the spread of the virus in classrooms. If students' absence data are available, we can construct the absence rate in winter, at which time the number of flu infections increases, for all classes, and utilize it as an outcome variable indicating a flu epidemic in classrooms. We can also construct the absence rate in summer, in which sickness is less likely to be influenced by within-class transmission and which can be interpreted as a proxy of students' health capital. The availability of the absence rate in summer allows us to implement a placebo test to confirm whether students health capital is related to our instruments or not. Evaluation of the effectiveness of class closure policy for prevention of subsequent spread of flu in class and school reviewed in Cauchemez et al. (2009) is another important topic remaining for future research.

Second, more detailed heterogeneous effects of student and teacher characteristics should be analyzed. For example, the combination of class size reduction and allocating teachers with strong ability to manage students may boost class size effects.

Appendix

A.1 Extra Descriptive Statistics

[Figure 5 about here.]

Figure 5 shows a distribution of the absentee rate in classes just before class closures after controlling for school, year, and grade FEs. As explained, we draw the figure using the data for classes actually closed due to a flu epidemic, because the data of absence rates are available only at class level. To calculate the absentee rate controlled by the FEs, we regress the absentee rate on the FEs and add a constant term and an error term obtained from the regression. A R^2 of the regression is 0.4585. According to Figure 5, mean and median are almost the same as those for raw absentee rates. The standard deviation of the distribution is about 26.4% smaller than that for raw absentee rates, while there still remains a variation in the absentee ratio.[35]

[Table 5 about here.]

Next, we discuss a frequency of class reshuffling in public schools operated by City X using Table 5 summarizing the proportion of students in a class with the same class number as the previous school year for each class between 2015 and 2017. In Japan, when students get promoted to the next grade without reshuffling classes, it is common that class numbers do not change. For example, the 3rd graders belonging in a class, "3-1", move to the class of "4-1" when they get promoted without reshuffling classes. Therefore, if all students in one class have the same class numbers as that in the previous school year, the students should get promoted to the next grade without reshuffling the class; in other words, the class could be defined as a non-reshuffled class. According to Table 5, the proportion of non-reshuffled classes is about 21.4% of in elementary schools and about 0.1% in middle schools; in other words, in elementary schools and middle schools, about 78.6% and about 99.9% of classes are estimated to be reshuffled, respectively (Column (1)). In City X, the proportion of non-reshuffled classes when students get promoted to 2nd, 4th and 6th grade ranges between 32.3% and 40.8%, and is much higher than that when students get promoted to 3rd and 5th grade. This tendency does not change when we utilize other cutoff values (Columns (2)-(5)).

A.2 Robustness Checks

In this appendix, we show some robustness checks for our main results.

[35] Standard deviations for the raw rates and the rate controlled by the FEs are .0978 and .0720, respectively.

[Table 6 about here.]

Table 6 summarizes estimation results by adding other types of fixed effects into the results reported in Columns (1) and (2) Table 3. Columns (1) and (5) report again the results in Columns (1) and (2) in Table 3, respectively. In addition to year, grade and school fixed effects (FEs), we estimate the model with year-school FEs (Columns (2) and (6)), grade-school FEs (Columns (3) and (7)) and both year-school FEs and grade-school FEs (Column (4) and (8)). The year-school FEs could capture unobserved characteristics in a year and in a school such as school principals' characteristics and school nurses' characteristics. We utilize the grade-school FEs to try to capture classroom buildings' characteristics. In Japan, classes belonging to the same grade are often assigned classrooms on the same floor in a row, and the classroom used by a grade is often the same even if the year changes. In other words, the classrooms used by students in grade X of school A are fixed, and students move to different classrooms when they move to the next grade. If this is the case, the grade-school FEs could control for classroom buildings' characteristics. According to Table 6, our estimation results are robust for the 2SLS models. The estimates of class sizes are positive and statistically significant after controlling for the FEs, and when we utilize both year-school FEs and grade-school FEs , the magnitude of the estimate is slightly larger than that in Column (5).

[Table 7 about here.]

Table 7 summarizes estimation results using other cutoffs of the class size dummy variable. We utilize 26, 28, and 30 as other cutoffs than 27. According to Table 7, by changing the cutoff values, in the 2SLS models, the estimates of class size dummies become negative and statistically significant at 5% level. The results show that the smaller the cutoff, the larger the magnitude of estimates. This tendency is consistent with the nonlinearity of the effect of class sizes estimated in Section A.3.

A.3 Estimation Results Using Other Functional Forms of Class Size

[Table 8 about here.]

[Table 9 about here.]

[Figure 6 about here.]

[Figure 7 about here.]

This appendix briefly summarizes the estimation results for the class size effect using the quadratic and cubic functions of class sizes. We estimate Equation (1) using class size, squared class size, and cubed class size. Table 8 shows the estimation results with full sample. We report not only coefficients of class size variables but also Kleibergen–Paap rk Wald F-statistics for weak identification and p values for testing, with the hypothesis that all of the coefficients are zero.

According to Table 8, when we used the quadratic function, among both OLS and 2SLS models, the coefficient of class size and that of squared class size are insignificant, while the p value for the test is 0.056 when we use the 2SLS model. In the case of cubic function, among both OLS and 2SLS, all of the coefficients are statistically significant. For both quadratic and cubic functions, the Kleibergen–Paap rk Wald F-statistics are over 10.

Table 9 summarizes the estimated marginal effects of class size using the estimated coefficient in Columns (2) and (4) of Table 8, while Figures 6 and 7 plot the marginal effects with 95% confidence intervals. The standard errors are calculated using the delta method. According to Columns (1) of Table 9, the marginal effects of class size are upward-sloping and statistically significant at least 10% between class sizes of 29 and 37 when we utilize the quadratic function of class sizes. Column (2) of Table 9 shows that the marginal effects of class size are statistically significant at least 10% between class sizes of 27 and 34.[36] The estimation result implies that if students do not have a certain level of physical distance to prevent exposure to droplets, class size reductions are not effective to prevent flu epidemics in classrooms. The result also implies that once students get enough physical distance, class size reduction is no longer effective to decrease the probability of flu infection.

[36] Note that marginal effects for the model with the cubic function are negatively estimated between class sizes of 38 and 40. The negative marginal effects are due to the functional form of class sizes, and are statistically insignificant.

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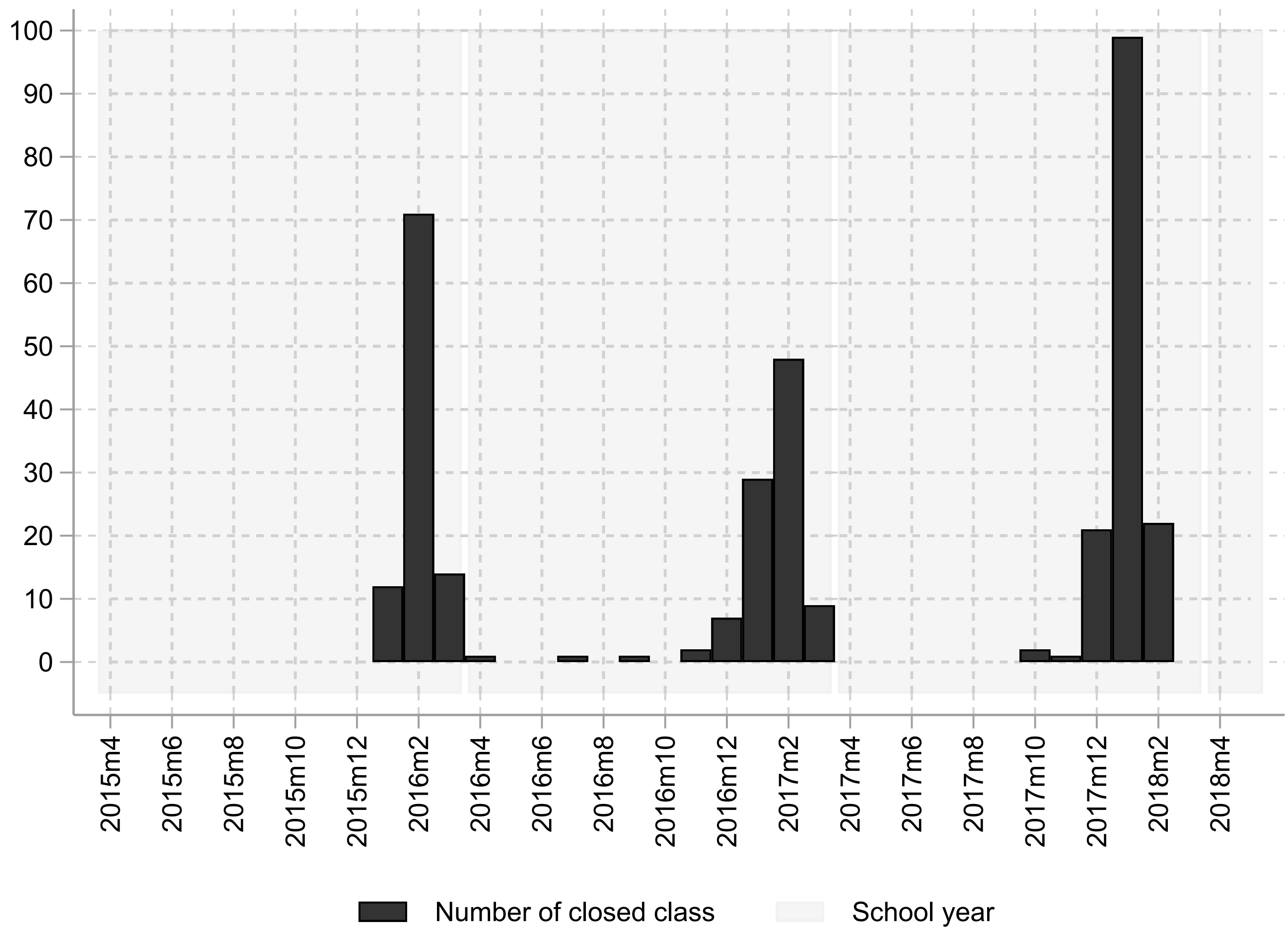


Figure 1: Timing of Class Closure Due to a Flu Epidemic in City X

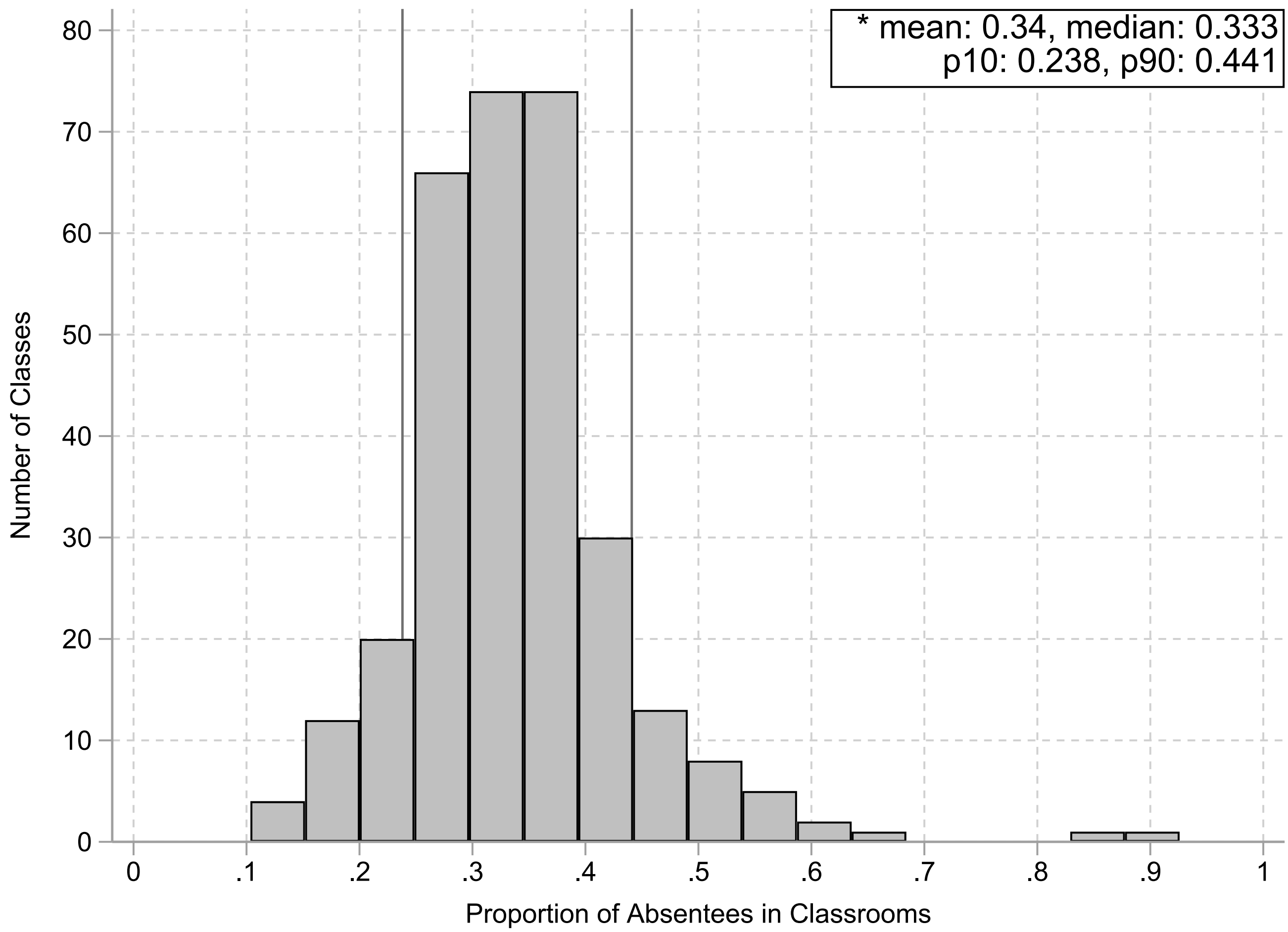
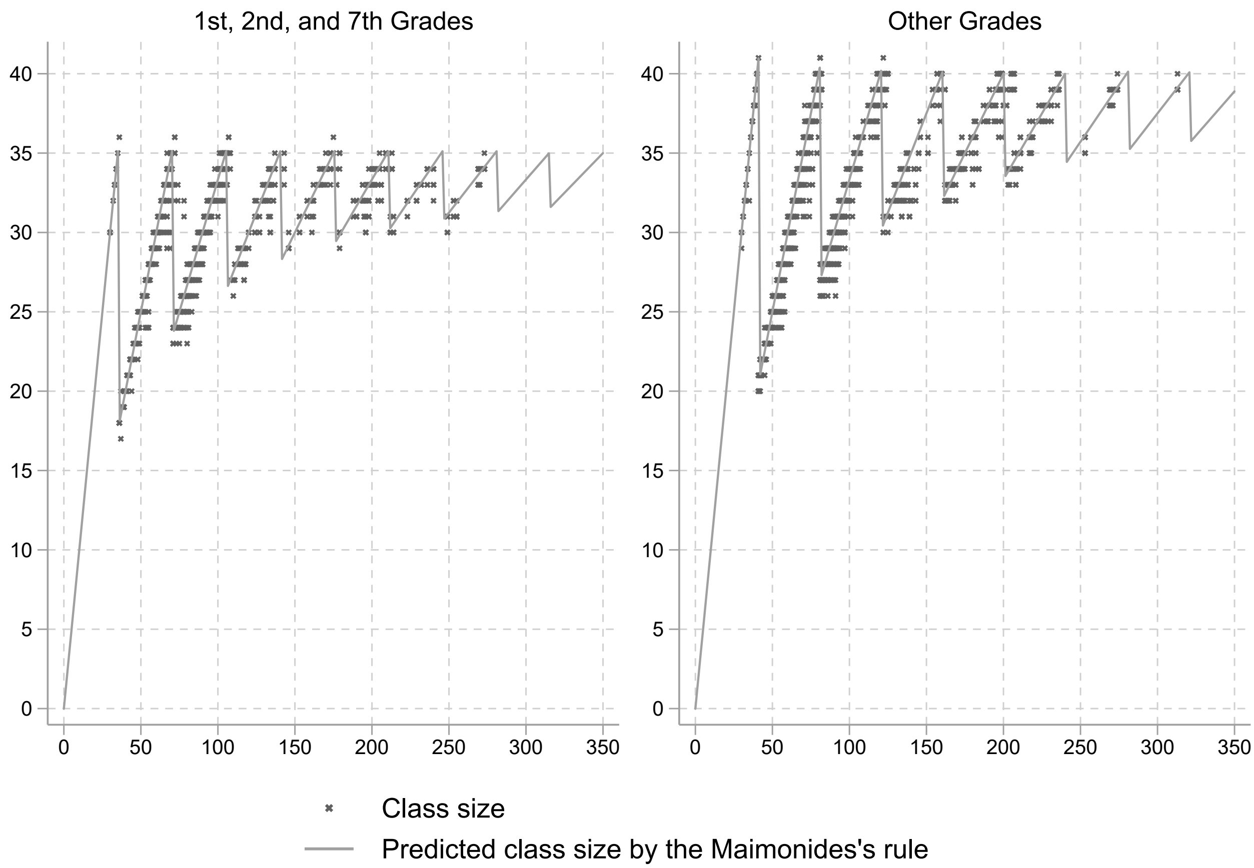


Figure 2: Absentees Ratio in Closed Classes Before the Closure

*We draw the figure using the data for classes actually closed due to a flu epidemic because the data of absence rate are available only for the classes.



* X-axis shows the number of students in a grade in school.

Figure 3: Actual and Predicted Class Sizes

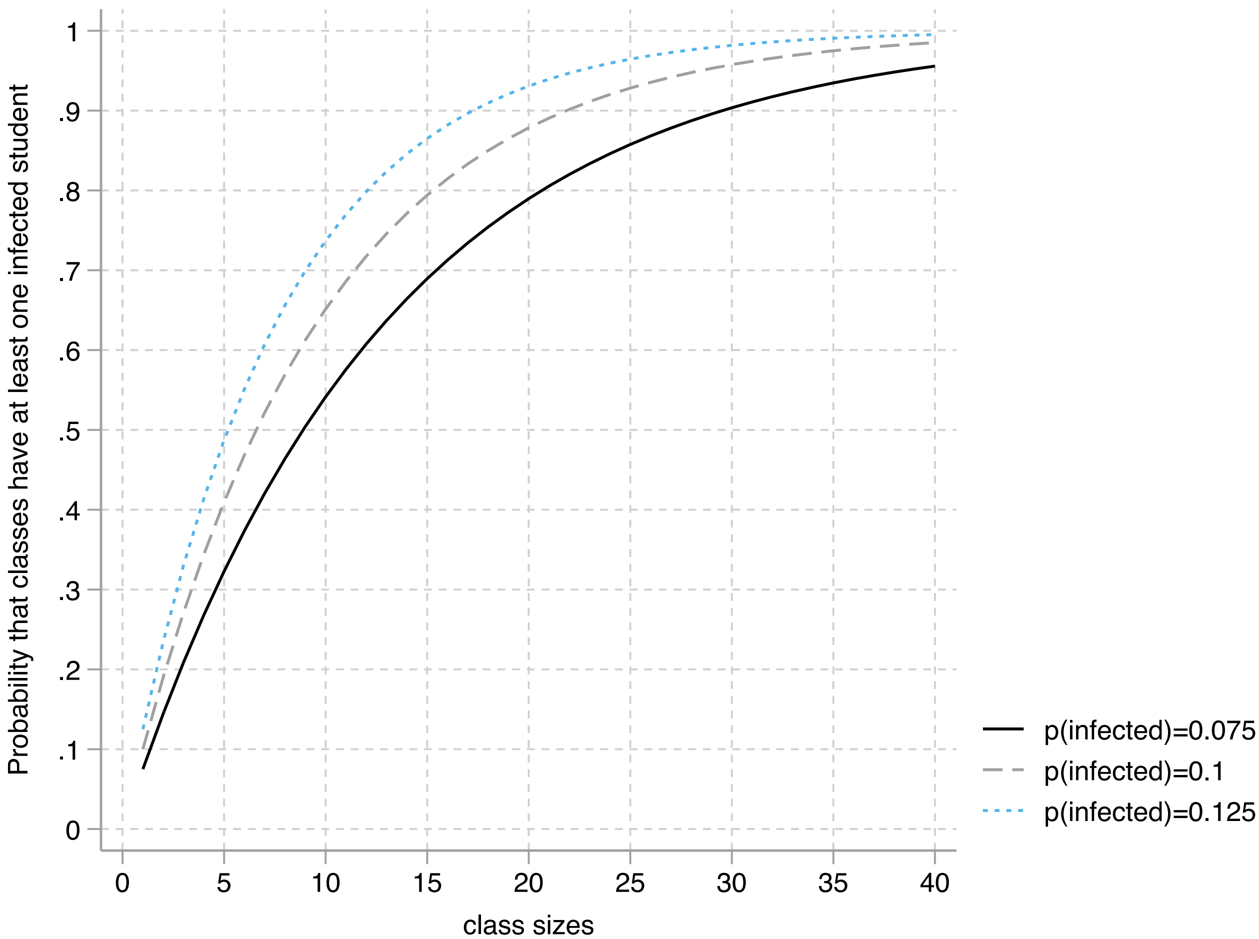


Figure 4: Class sizes and Simulated Probability That Classes Have At Least One Infected Student

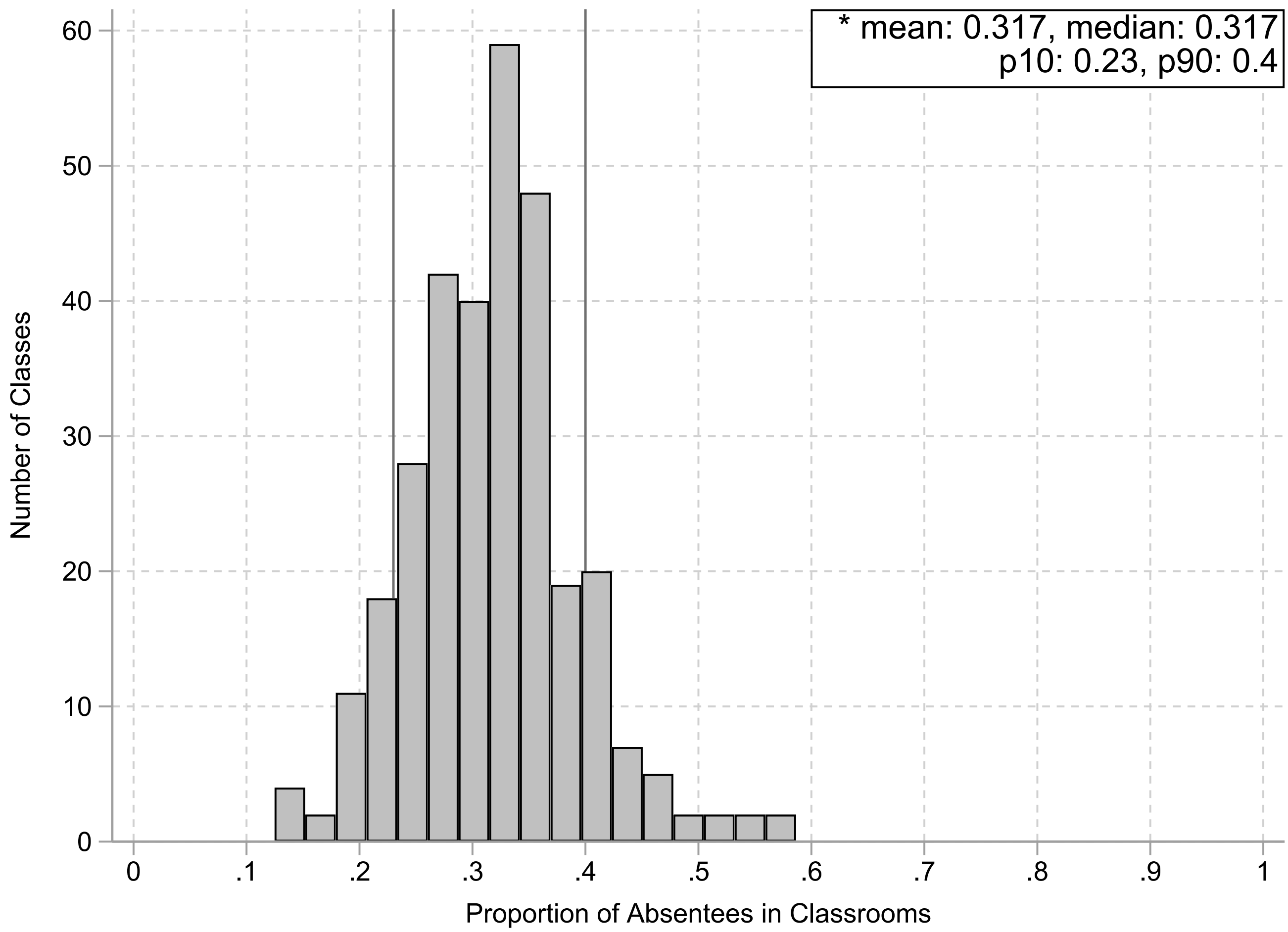


Figure 5: Absentees Ratio in Closed Classes Before the Closure After Controlling for School, Year and Grade Fixed Effects

*We draw the figure using the data for classes actually closed due to a flu epidemic because the data of absence rate are available only for the classes.

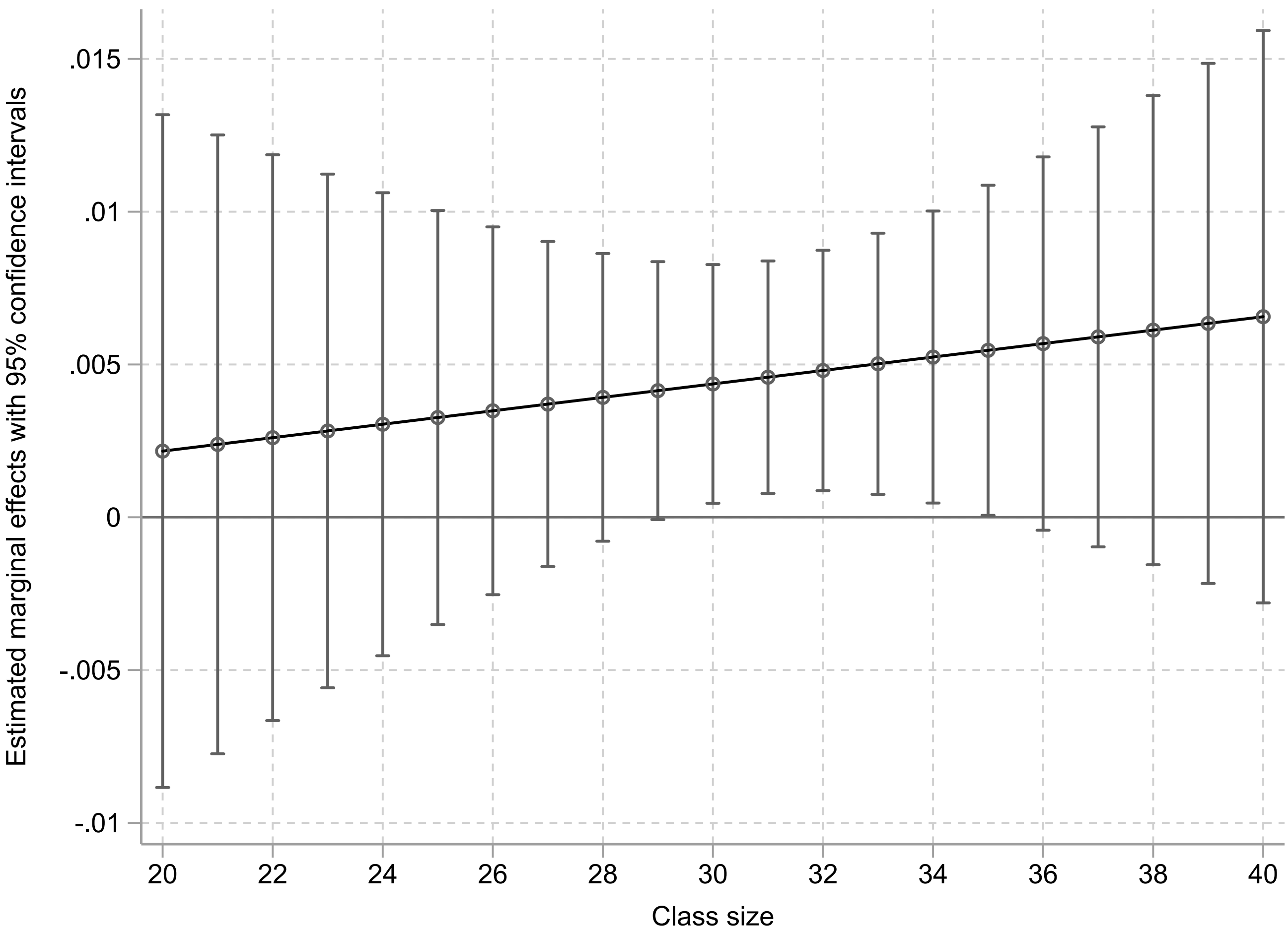


Figure 6: Marginal Effects of Class Sizes for 2SLS Calculated Using Column (2) of Table 8

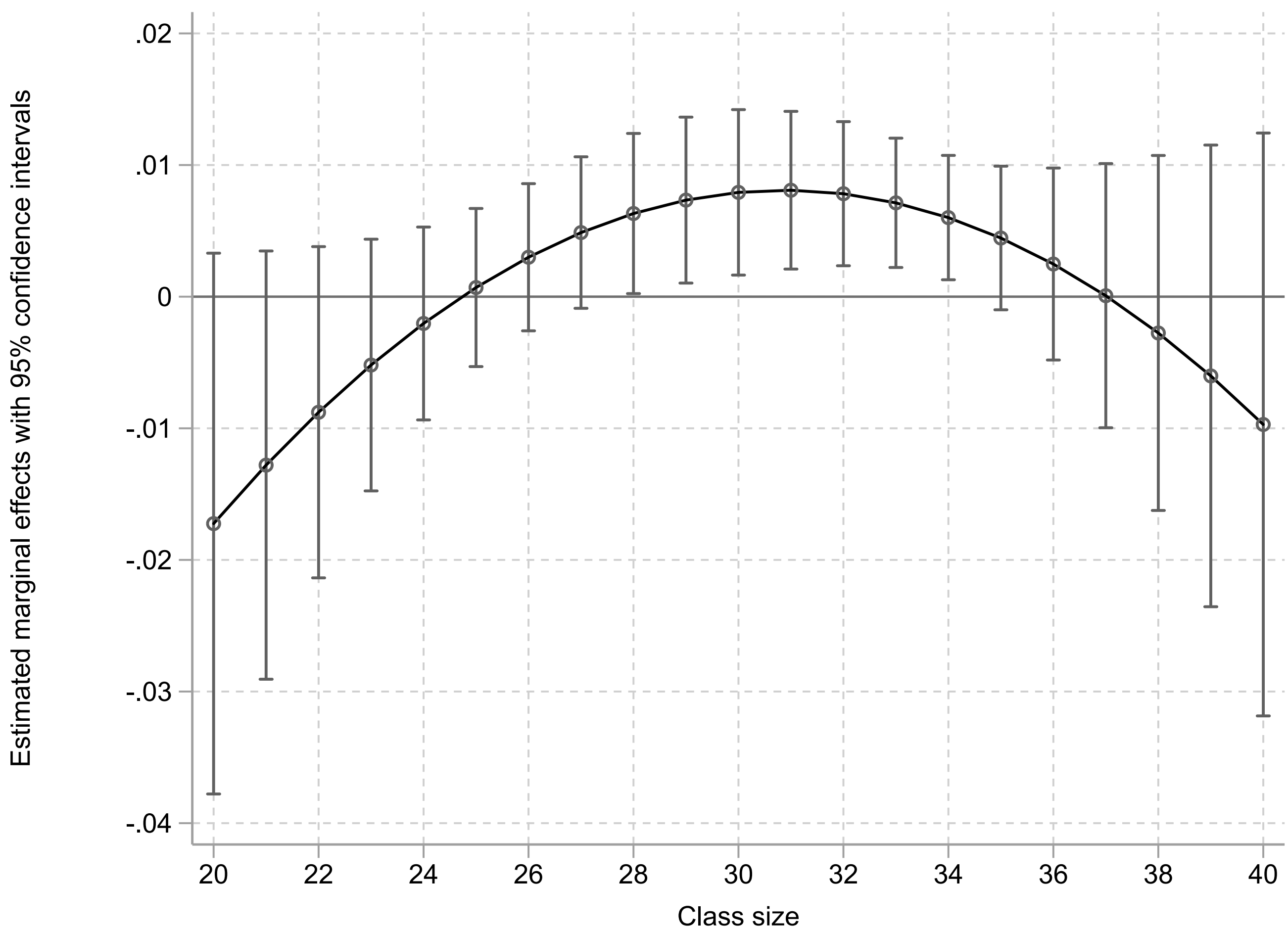


Figure 7: Marginal Effects of Class Sizes for 2SLS Calculated Using Column (4) of Table 8

Table 1: Summary Statistics

	(1) Whole	(2) 1st-3rd	(3) 4th-6th	(4) 7th and 8th	(5) 9th
Class size	31.539	29.932	31.388	33.233	34.963
	[4.381]	[3.938]	[4.438]	[3.815]	[3.693]
Class size ≤ 27	0.173	0.256	0.175	0.078	0.030
	[0.378]	[0.437]	[0.380]	[0.269]	[0.170]
Class Closure	0.086	0.118	0.074	0.076	0.030
	[0.281]	[0.323]	[0.261]	[0.265]	[0.170]
Number of students in a grade in school	105.928	87.576	82.540	156.991	159.521
	[54.677]	[38.773]	[31.018]	[59.139]	[60.950]
Girl ratio	0.489	0.484	0.494	0.494	0.484
	[0.059]	[0.061]	[0.063]	[0.048]	[0.053]
Observations	4271	1582	1468	818	403

Mean values and standard deviations are reported. Standard deviations are in square brackets.

Table 2: Relationship Between Class Size and Absentee Ratio Before Class Closure

	(1)	(2)
Class size	-0.0022	
	(0.0015)	
Class size ≤ 27		0.0122
		(0.0168)
Observations	311	311
Overall mean	0.340	
%Δ from overall mean	-0.7	
Mean in bigger class		0.334
%Δ from mean in bigger class		3.7

The unit of observation is cases of class closure. The dependent variable is the absentee rate just before class closure. Standard errors robust against school-level clustering are in parentheses. All models include number of students in a grade in a school, squared number of students in a grade in a school, girl ratio, grade fixed effects, and year fixed effects. Inference: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Effects of Class Size on Class Closure

	(1) OLS	(2) 2SLS	(3) 2SLS ±6	(4) OLS	(5) 2SLS	(6) 2SLS ±6
Class size	0.0031*	0.0046**	0.0051*			
	(0.0016)	(0.0019)	(0.0027)			
Class size ≤ 27				-0.0281*	-0.0757**	-0.0878*
				(0.0156)	(0.0331)	(0.0466)
Observations	4271	4271	1373	4271	4271	1373
1st stage F-statistics		1074.41	304.08		204.37	159.59
Overall mean	0.086	0.086	0.098			
%Δ from overall mean	3.6	5.3	5.2			
Mean in bigger class				0.087	0.087	0.101
%Δ from mean in bigger class				-32.2	-86.6	-87.1

Dependent variables are the class closure dummy variables. Standard errors robust against school-level clustering are in parenthesis. All models include number of students in a grade in a school, squared number of students in a grade in a school, girl ratio, grade FEs, school FEs, and year FEs. In columns named "2SLS ±6", we use the classes in the schools with enrollments between "cutoff value 6" and "cutoff value + 6". Inference: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Heterogeneous Effects by Grades

	1st, 2nd, and 3rd		4th, 5th, and 6th		7th and 8th	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS	(5) OLS	(6) IV
Class size	0.0017	0.0028	0.0045**	0.0061**	0.0087*	0.0134**
	(0.0030)	(0.0038)	(0.0019)	(0.0025)	(0.0047)	(0.0068)
Observations	1582	1582	1468	1468	818	818
1st stage F-statistics		607.48		448.38		117.02
Overall mean	0.118	0.118	0.074	0.074	0.076	0.076
%Δ from overall mean	1.4	2.4	6.1	8.3	11.4	17.7

Dependent variables are the class closure dummy variables. Standard errors robust against school-level clustering are in parenthesis. All models include number of students in a grade in school, squared number of students in a grade in school, girl ratio, grade FEs, school FEs, and year FEs. Inference: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Proportion of Students with the Same Class Number as the Previous School Year for Each Class

	Classes with proportion of students having same class numbers as those in the previous school year is ...				
	(1) 100%	(2) 80% or more	(3) 85% or more	(4) 90% or more	(5) 95% or more
Elementary Schools	0.214	0.456	0.455	0.446	0.388
2nd graders	0.325	0.717	0.717	0.690	0.599
3rd graders	0.002	0.008	0.008	0.008	0.004
4th graders	0.323	0.774	0.768	0.756	0.628
5th graders	0.008	0.018	0.018	0.018	0.014
6th graders	0.408	0.748	0.748	0.746	0.682
Middle schools	0.001	0.007	0.007	0.006	0.004
7th graders	0.000	0.000	0.000	0.000	0.000
8th graders	0.003	0.010	0.010	0.010	0.008
9th graders	0.000	0.010	0.010	0.007	0.005

Table 6: Robustness Checks: Other Types of Fixed Effects

	OLS				2SLS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Class size	0.0031^{*}	0.0030^{*}	0.0039^{*}	0.0038	0.0046^{**}	0.0044^{**}	0.0065^{***}	0.0065^{***}
	(0.0016)	(0.0018)	(0.0021)	(0.0023)	(0.0019)	(0.0020)	(0.0024)	(0.0025)
Observations	4271	4271	4271	4271	4271	4271	4271	4271
1st stage F-statistics					1074.41	1081.04	616.34	608.01
FEs:								
(a) year, grade, school	yes	yes	yes	yes	yes	yes	yes	yes
(b) (a) + year×school		yes		yes		yes		yes
(c) (a) + grade×school			yes	yes			yes	yes
(d) (c) + year×school				yes				yes

Dependent variables are the class closure dummy variables. Standard errors robust against school-level clustering are in parentheses. All models also include number of students in a grade in school, squared number of students in a grade in school and girl ratio. Inference: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Robustness Checks: Other Cutoffs of Class Size Dummy Variable

	OLS			2SLS		
	(1)	(2)	(3)	(4)	(5)	(6)
Class size ≤ 26	-0.0192			-0.0977**		
	(0.0184)			(0.0443)		
Class size ≤ 28		-0.0304*			-0.0584**	
		(0.0160)			(0.0247)	
Class size ≤ 30			-0.0229			-0.0488**
			(0.0139)			(0.0202)
Observations	4271	4271	4271	4271	4271	4271
1st stage F-statistics				99.63	338.19	399.74

Dependent variables are the class closure dummy variables. Standard errors robust against school-level clustering are in parentheses. All models include number of students in a grade in school, squared number of students in a grade in school and girl ratio. Inference: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: Estimation Results Using Class Size, Squared Class Size, Cubed Class Size

	Quadratic		Cubic	
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS
Class size	0.01269	-0.00223	-0.26422***	-0.19597*
	(0.01279)	(0.01503)	(0.09268)	(0.10813)
Squared class size	-0.00015	0.00011	0.00903***	0.00661*
	(0.00020)	(0.00024)	(0.00310)	(0.00370)
Cubed class size			-0.00010***	-0.00007*
			(0.00003)	(0.00004)
Observations	4271	4271	4271	4271
Kleibergen-Paap rk Wald F statistic		174.74		50.00
Joint test for coeffcients of class size	0.150	0.056	0.013	0.184
Overall mean	0.086		0.086	

Dependent variables are the class closure dummy variables. Standard errors robust against school-level clustering are in parentheses. All models include number of students in a grade in school, squared number of students in a grade in school, girl ratio, grade FEs, school FEs, and year FEs. Inference: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 9: Marginal Effects of Class Sizes for 2SLS Calculated Using Table 8

	(1) Quadratic		(2) Cubic	
	Marginal effects	Standard errors	Marginal effects	Standard errors
Class size				
20	0.0022	(0.0056)	-0.0172	(0.0105)
21	0.0024	(0.0052)	-0.0128	(0.0083)
22	0.0026	(0.0047)	-0.0088	(0.0064)
23	0.0028	(0.0043)	-0.0052	(0.0049)
24	0.0030	(0.0039)	-0.0020	(0.0037)
25	0.0033	(0.0035)	0.0007	(0.0031)
26	0.0035	(0.0031)	0.0030	(0.0029)
27	0.0037	(0.0027)	0.0049*	(0.0029)
28	0.0039	(0.0024)	0.0063**	(0.0031)
29	0.0041*	(0.0022)	0.0073**	(0.0032)
30	0.0044**	(0.0020)	0.0079**	(0.0032)
31	0.0046**	(0.0019)	0.0081***	(0.0031)
32	0.0048**	(0.0020)	0.0078***	(0.0028)
33	0.0050**	(0.0022)	0.0071***	(0.0025)
34	0.0052**	(0.0024)	0.0060**	(0.0024)
35	0.0055**	(0.0028)	0.0045	(0.0028)
36	0.0057*	(0.0031)	0.0025	(0.0037)
37	0.0059*	(0.0035)	0.0001	(0.0051)
38	0.0061	(0.0039)	-0.0028	(0.0069)
39	0.0063	(0.0043)	-0.0060	(0.0089)
40	0.0066	(0.0048)	-0.0097	(0.0113)
Observations	4271		4271	

This table summarizes the marginal effects reported in Figures 6 and 7, and their standard errors. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.